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Innovative Design Education in a Global Distance Learning Setting

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Abstract

A lot has been written about how much the world has changed since the advent of Globalization and that engineering education, in response to that needs to be addressed from a more holistic point of view. In this paper, we present an innovative approach to design education that represents a transformation from traditional in-class education to a globally distributed collaborative distance learning setting that mirrors real-world design experience.

Key Words: Design education, distance learning, virtual learning environment, personalized learning, mass collaboration, collective learning.

I. Introduction

The world of technology is becoming increasingly complex and dynamic. The skills that were considered valuable yesterday are becoming the commodities of today and tomorrow [1,2]. Realizing how much the world has changed over the past twenty years, it becomes apparent that this change needs to be better reflected in the way engineering designers are educated and prepared for to work in [3-6]. Complex social networks, consisting of millions of individuals, have formed over the Internet through emerging Web 2.0 technologies such as blogs, discussion boards, wikis, collaboration networks such as Facebook, video networks such as YouTube, and countless others. Information is readily available to everyone through the Web, anytime and anywhere. Individuals,

who have never met *physically*, i.e., in person, are already collaborating on the development of complex products and services for major companies, solving challenging problems that are openly ‘crowd sourced’ to the community of interested engineers and scientists. For the next generation of engineers, this new paradigm will be the new norm. Their number one material to work with will be information, their final product(s) will be intellectual property and innovation, and their generation is becoming known as the *generation of knowledge workers*.

As alluded to before, over the past two decades web-based technologies have brought about revolutionary changes in the way organizations conduct business. Organizations are increasingly transforming into decentralized supply and demand networks. According to Friedman [1], we have now reached the era of Globalization 3 (G3), in which individuals have the power to collaborate and compete globally.

Globalization 3 has led to the emergence of various new paradigms related to breakthrough innovation that are characterized by the self-organization of individuals into loose networks of peers to produce goods and services in a very tangible and ongoing way. Examples of such paradigms include mass collaboration [12], collective innovation [13], collective invention [14], user innovation [15], crowd sourcing [16], open innovation [17], and community-based innovation [18].

New organizational structures based on self-organizing communities are emerging to complement traditional hierarchies. According to Tapscott and Williams [12], the new principles for success in Globalization 3 are a) openness to external ideas, b) individuals as peers, c) sharing of intellectual property, and d) global action. In such emerging organizations, individual success is defined by the recognition gained through contributions towards a common goal rather than by following the directions from the top management. An organization's success is determined by its ability to integrate talents of dispersed individuals and other organizations. Hence, the skills and competencies required for success in the G3 world vary from the ones required for success in the Globalization 1 or Globalization 2 eras.

In addition to this, the overall workplace characteristics of the near future are expected to be very different from the current ones. According to [19], by the year 2020:

- The workplace will be highly personalized and social.
- Employers will need to adjust to the unprecedented challenge of having up to five generations of individuals working together.
- Employers can expect to manage employees with vastly different interests and life experiences from varied regional, ethnic, and cultural backgrounds.
- Employers must provide fully individualized benefits and services.
- Traditional offices and nine-to-five work schedules will be largely passé.
- Knowledge workers will dominate. Lifelong learning will be the rule.

- Employees will expect and demand robust internal and external online connections.
- The future HR staff will include positions that do not yet exist, such as ‘talent developing agent’.

Similarly, Benko and Weisberg [20] describe an ongoing shift away from the traditional *career ladder* model to a *career lattice*. That is, a model to allow for customized and flexible career paths based on new organizational forms that better fit the workforce of near tomorrow. In summary, for our graduates to succeed in the world of near tomorrow, we must teach them to learn and play in a whole new game of design and engineering.

Given this complex and dynamic environment, the key question we pose is: *How can we better educate the engineering designers of near tomorrow?* While there is a broad agreement that engineering education needs to change based on the current dynamics of globalization, innovation-centric value creation, and such, there appears to be little tangible advice rooted in practical experience as to how exactly that change is best to occur. One step in the right direction, of which many educators agree, is that engineering education should reflect upon a more holistic point of view [7-9]. There ought to be a better symbiosis of societal needs, technologies, cross-disciplinary integration and associated educational activities. Our task at hand is to prepare engineers who are capable of identifying and solving problems that do not yet exist with tools and methods that have not yet been invented. This includes, what at a later point will be introduced as *21st century dilemma management*. In essence, the big challenge boils down to educating students in the art of *learning how to learn* and to empower them to take charge of their own education within the context of an ever-increasing amount of subject matter to be comprehended. We believe that the competitiveness of the next generation of engineers in general will no longer be defined solely by their knowledge and skills. A key differentiator of leaders and followers will be their ability to *create* their own knowledge and constantly improve and update their competencies in an ever changing world.

We believe that, in light of the above context, engineering education in general should be augmented with ‘game changing’ strategies to better prepare students for the world of near tomorrow, in which distributed value creation in an interconnected world will be the new normal [10,11].

Our ‘laboratory’ for experimenting with innovative design education is a graduate level engineering design course offered at Georgia Institute of Technology every spring, namely, ME6102 Designing Open Engineering Systems. We have jointly orchestrated this course for several years. An overview of the course context, content and structure, the way it is implemented, the underlying educational framework, and lessons learned are presented in the following sections.

The remainder of the paper is organized as follows. In Section 2, our approach to facilitating learning in the context of ME6102 is presented. This is followed by the underlying educational framework in Section 3 and an overview of the actual course content in Section 4. In Section 5 we give an overview of how we tie important business-related aspects to the task of designing engineering systems. Section 6 provides an overview of the technology we are using for collaborative engineering design and design education in a distance learning setting. Finally, we provide closure in Section 7.

II. Facilitating Learning in ME6102

ME6102 Designing Open Engineering Systems is a graduate level design course offered at Georgia Institute of Technology. It is taken by students with diverse backgrounds from a variety of engineering and science disciplines. The course is offered in both live and distance learning modes. The student body comprises of participants from the Georgia Tech Atlanta, Savannah, and Lorraine (France) campuses as well as distance-learning students from across the US. In addition, we have participants from other countries, such as the Netherlands or even the Arabian Emirates. Most students take ME6102 after they have taken an introductory engineering design course (for example, ME6101 Engineering Design) in which they have become familiar with a systematic design approach, for example Pahl and Beitz [21].

From a core technical point of view ME6102 is mainly concerned with the design of Open Engineering Systems (OES). Open Engineering Systems are defined as “*systems of industrial products, services, and/or processes that are readily adaptable to changes in their environment, which enable producers to remain competitive in a global marketplace through continuous improvement and indefinite growth of an existing technological base*” [22]. In addition, over the course of the semester students are introduced to a selection of additional design-related topics, including mass customization of products, design of product platforms, modular design, robust design, decision-making in design, as well as an introduction to Systems Engineering and the famous Vee Model [23]. Since we assume that the reader is familiar with the design-related subject matter, we do not go into further detail here.

III. Educational Framework of Reference

In this section, we provide an overview of the educational framework that influences our teaching philosophy and upon which our approach to teaching engineering design in a globally disturbed collaborative setting is based. Our framework is mainly anchored in Bloom’s Taxonomy of Learning, aimed at fostering deep learning among students through problem-based learning and student-centered instructional techniques. In addition, it features elements of competency-based education, collaborative/collective learning, the development of a learning community, and ties in well with the relatively new idea of threshold concepts and transformational education.

Bloom’s Taxonomy of Learning: In 1956, Bloom [32] developed a classification of levels

of intellectual behavior important in learning. Bloom identified six levels within the cognitive domain (see Figure 1), from the simple recall or recognition of facts, as the lowest level, through increasingly more complex and abstract mental levels, to the highest order, which is classified as evaluation. These six levels are: (1) knowledge, (2) comprehension, (3) application, (4) analysis, (5) synthesis, and (6) evaluation.

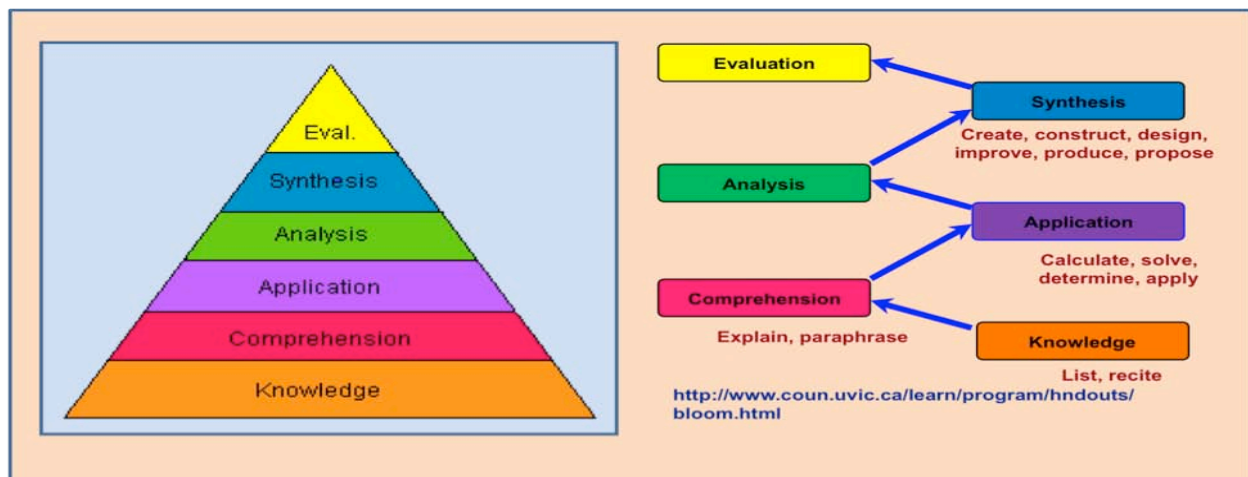


Figure 1: Bloom's Taxonomy of Learning.

Bloom's taxonomy provides a systematic way of describing how a learner's performance grows in complexity when mastering academic tasks. It can thus be used to define curriculum objectives, which describe where a student should be operating. In addition, Bloom's taxonomy provides a powerful means to assess students' performance, justify associated grades, and at the same time provide students with feedback as to how to improve their performance. In a truly constructively aligned curriculum it facilitates deep learning as the activities are designed for that purpose.

At the beginning of ME6102 all students are introduced to Bloom's Taxonomy and it is emphasized that our intention is to help our graduate students reach the top levels of the taxonomy. Interestingly, Bloom's Taxonomy resembles Maslow's famous Hierarchy of Needs [33] if competencies are considered needs in terms of becoming successful in the G3 world. While there are many other taxonomies of learning that we could have used for the same purpose we decided to choose Bloom's traditional taxonomy simply because it is something that, based on our experience, engineering students find natural and easy to grasp.

Collaborative and Collective Learning: Today, the term collaborative learning stands for a variety of student-centered educational approaches that involve joint intellectual

effort by learners and instructors. It refers to educational methodologies and learning environments in which learners engage in common tasks in which each individual depends on and is accountable to each other. Groups of students usually work together in order to understand something, grasp a meaning, or develop a solution to a problem. The theory of collaborative learning is tied together by a number of important assumptions about learners and learning processes. These include (a) that learning is an active, constructive process in which learners create new knowledge by using, integrating and reorganizing their prior knowledge; (b) that learning depends on rich context, which influences the success of learning significantly; (c) that learners are diverse in terms of background, knowledge, experience and learning styles; and (d) that learning is inherently social, which makes student interaction an important part of education. All of these aspects of learning are supported by the means of collaborative learning where students solve problems and create knowledge in a diverse group setting.

The term collaborative learning also refers to a collection of tools, which learners can use to collaborate, assist, or be assisted by others like they are used in e-Learning and distance learning environments. Such tools include virtual classrooms, chat rooms, discussion threads, as well as application and document sharing. The term collective learning is not uniquely defined and most widely used in the context of vocational education. There is a clear distinction between learning in social interactions (with and from others) and collective learning, where the learners consciously strive for common learning and/or working outcomes. They use the term collective learning for educational systems, in which the intended outcomes (and perhaps, the process of learning), are collective. This is a key point of relevance with regard to the pedagogical approach presented in this paper. The three major forms of collective learning are (a) learning in networks, (b) learning in teams and (c) learning in communities.

The Learning Organization: Another key pillar of our educational framework is the formation of a learning community in a distributed distance learning setting. The blueprint for this is the model of the Learning Organization (LO) as introduced by Peter Senge in his famous 1990s book 'The 5th Discipline' [29]. According to Senge, a Learning Organization is "an organization that facilitates the learning of all its members and consciously transforms itself and its context". A learning organization exhibits five main characteristics: (1) systems thinking, (2) personal mastery, (3) mental models, (4) a shared vision, and (5) team learning.

An obvious issue with introducing this paradigm of the Learning Organization into the classroom environment of ME6102 is that it was mainly developed for companies, based on the business models and practices of the 1990s. However, our graduate students, future engineers, are required to form such a LO within their distributed learning environment. Hence, one of our key activities is to analyze the original model of the LO and augment it to better fit the needs of our educational setting and the characteristics of the G3 world of near tomorrow.

Scaffolding: One of the primary goals in ME6102 is to provide personalized learning in a collaborative environment. This is realized through four instructional cornerstones: scaffolding, reflective practice, customization, and collaboration. A combination of these utilizes a variety of educational approaches to foster deep learning among students. The scaffolded part frames the content of the course with the “Question for the Semester” (Q4S) and several associated assignments. The assignments are structured (scaffolded) and provide opportunity for individualization. This ensures that everybody in class works in the direction intended by the course orchestrators. The lectures are used to connect the assignments to the customized components of the course. The lectures are also used to convey core course content and also cover additional aspects that may help students with their assignments. The collective knowledge and experience of the students enrolled in our course is harnessed to create a collective solution to the design problem (group project) and the answer to the Q4S that could not be accomplished by an individual.

Reflective Practice through *Observe-Reflect-Articulate*: In a mass customized course the articulation of individual learning is crucial since it is the prerequisite for the evaluation of the progress. Usually students are not used to this and have difficulties with the articulation of their learning. They are used to show their learning during exams in a strictly predefined way. Here the students require a learning construct that provides guidance through the entire learning process and helps them to identify and express their learning and new knowledge. Therefore, in ME6102, the Observe-Reflect-Articulate (ORA) construct [27] is introduced to the students at the beginning of the semester. It consists of three phases:

1. Observation, in which existing knowledge is reviewed from different sources like lecture, literature, magazines or newspapers.
2. Reflection, in which the observed knowledge is synthesized by reflecting on given or self discovered questions.
3. Articulation, in which learning and new knowledge, gained from the first two phases, is expressed.

By following these steps during the submissions the students internalize the process of learning and deeply learn how to learn. This is one way of introducing students to what in education is referred to as ‘reflective practice, as introduced by Donald Schon [30].

Learning essays and group project: Learning essays are encouraged weekly submissions in which students review and explore topics from the lectures in context of their individual semester goals. To guide the students, at the end of each lecture guiding questions are suggested that may help them to better relate the lecture content to the big picture of the course. The students also have the freedom to choose other course-related themes for their learning essays. Since nothing in ME6102 is graded till the end of the semester (we provide formative assessment throughout the semester), the

students are more willing to take risks in choosing topics and developing new thoughts in their essays. If the orchestrators realize that a student is on a wrong track they express this in the individual feedback and provide guidance.

A core aspect of the learning essays is that the students apply and internalize the Observe-Reflect-Articulate construct for reflective practice and thus learn how to create new knowledge and enhance their critical thinking skills. At the end of the semester the students reflect on their learning in a Semester Learning Essay by relating it to a non-engineering analogy or metaphor. Examples of metaphors used by the students include football, cooking, golfing and writing poems. Here, the students can show insight and show that they really proceeded in achieving their semester goals.

The students are expected to validate a part of their answer to the Q4S through the group project. The validation is carried out using a construct called Validation Square [34,35], which originally was developed for validating design methods. Validation is an important aspect of the course because it helps students to learn how to critically evaluate their proposed answer to the Q4S.

Threshold Concepts and Transformational Learning: According to Meyer et al. [36], *“A threshold concept can be considered as akin to a portal, opening up a new and previously inaccessible way of thinking about something. It represents a transformed way of understanding, or interpreting, or viewing something without which the learner cannot progress. As a consequence of comprehending a threshold concept there may thus be a transformed internal view of subject matter, subject landscape, or even world view. This transformation may be sudden or it may be protracted over a considerable period of time, with the transition to understanding proving troublesome. Such a transformed view or landscape may represent how people ‘think’ in a particular discipline, or how they perceive, apprehend, or experience particular phenomena within that discipline (or more generally).”*

According to Meyer and Land [37], *“a threshold concept is likely to be:*

- *Transformative, in that, once understood, its potential effect on student learning and behavior is to occasion a significant shift in the perception of a subject, or part thereof.*
- *Probably irreversible, in that the change of perspective occasioned by acquisition of a threshold concept is unlikely to be forgotten, or will be unlearned only by considerable effort.*
- *Integrative; that is, it exposes the previously hidden interrelatedness of something.*
- *Possibly often (though not necessarily always) bounded in that any conceptual space will have terminal frontiers, bordering with thresholds into new conceptual areas*
- *Potentially (and possibly inherently) troublesome.”*

In ME6102, there are several *threshold experiences* for our students, who often are troubled and sometimes even shocked the first time they experience them. Here are selected examples:

- Instead of delving right into the subject matter of engineering design, students are asked to speculate about the world of design and manufacturing of the year 2030, based on current literature and developments, before learning about the engineering design process as we know it. By speculating about the world of 2030 they get a new perspective on the potential requirements of future engineering design processes. Thus, they are creating new knowledge beyond what they could learn from any given text book.
- The students are required to take stock of their current competencies and compare what they already have to the competencies a successful designer may need in future. Thereby, students are empowered to take charge of their own learning by articulating their individual associated learning objectives within the broader context of this course. At first, they cannot believe that the presented Question for the Semester really is their take-home exam and that they even have the right to tweak this question in response to their personal learning objectives. That way, they are encouraged to start shaping their own learning.
- Later on in the project phase, students are strategically guided to form a learning organization of self-organizing individuals that, collectively, leverage each other's competencies to solve a common problem. For about a week, they wait for the instructors to tell them exactly what to do to get started with their group project. However, we refuse to do so, and shortly afterwards a natural response of emerging leadership forms and students start taking on team roles based on their respective competencies and previous experiences.

IV. ME6102 Designing Open Engineering Systems – Course Framework

In this section, we present an overview of the learning activities of ME6102. As explained before, a key objective in this course is for students to learn how to learn, in the context of the G3 world, and technical domain of engineering design. An at-a-glance overview of the way in which learning is facilitated in ME6102 through a number of scaffolded activities is presented in Figure 2. Although the figure shows the specific implementation of Spring 2009, the overall framework is always identical. For a more detailed discussion of these elements one should refer to [26-28].

Question for the semester (Q4S): In personalizing a course, the challenge for the course orchestrators is to keep the students' efforts aligned with the objectives and topics intended. In the educational approach implemented in ME6102, this is achieved through a scaffolded component. It consists of structured assignments in a predefined form with firm due dates. These submissions are created to challenge the students, arouse their curiosity and let them discover issues related to the course they are personally interested in. In ME6102 this is realized by posing the "Question for the Semester" (Q4S) and several associated assignments that are scaffolded towards the answer to this question. In the first lecture, the Q4S is presented. Every student has to

answer this question as a take home exam that is due at the end of the semester. For example, the question for the semester in spring 2009 was:

“Imagine that you are operating a product creation enterprise in the era of Globalization 3 where individuals are empowered to participate in the global value network. Your brief is to identify the characteristics of the IT infrastructure to support technical collaboration that furthers open innovation.”

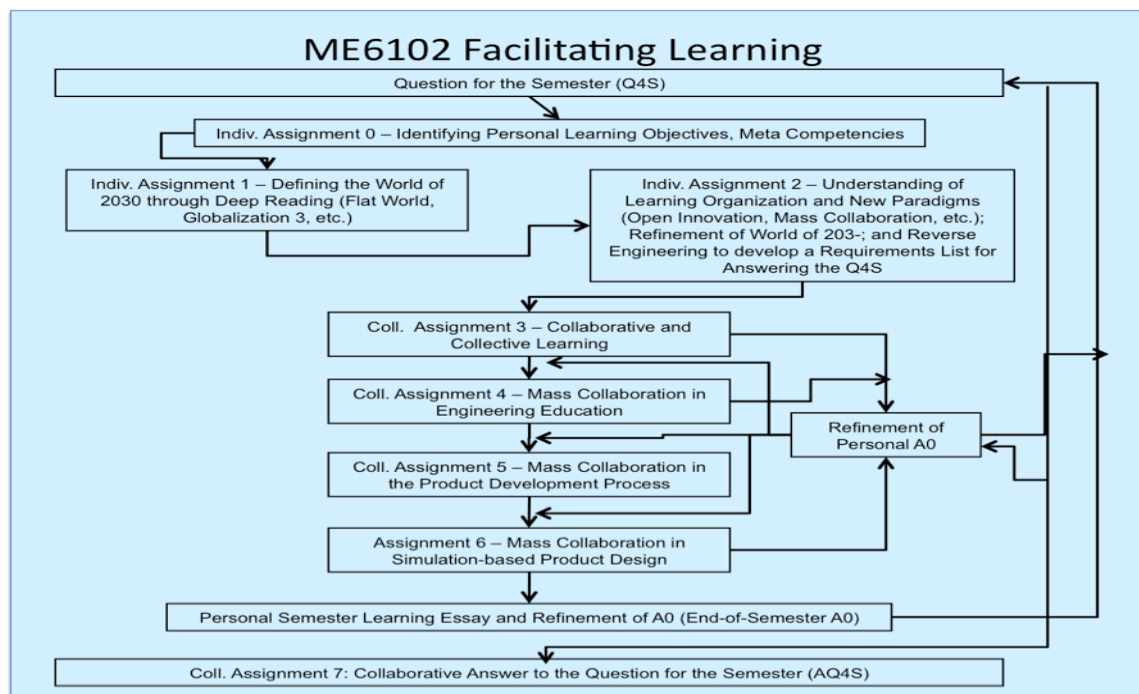


Figure 2: Facilitating learning in ME6102.

Every time we orchestrate the course, a similar question with a different focus is posed and serves as a foundation for the entire course. All learning activities are directed towards answering this question. To support the individual interests, the students are allowed to tweak and personalize this question according to their personal learning objectives (see Assignment 0). The changes a student is allowed to make to the Q4S are limited and have to be approved by the course orchestrators. In a mass customized course, this framing is particularly important to keep the students focused on their personal objectives. That way, the students can evaluate their work towards the answer of the Q4S and can prioritize their ideas.

Individual Assignment 0: In A0 students are required to identify the competencies they

wish to develop in the context of ME6102, the Q4S, and the G3 world as well as associated learning objectives. Since the student's knowledge and experience grow throughout the semester, these initial competencies and learning objectives have to be revisited and refined accordingly several times.

Individual Assignment 1: In A1 the students take a closer look at defining their world of 2030 and their views on what a design and manufacturing enterprise may look like 20 years from now. Expected deliverables are a vision for the engineering world of 2030, a vision of product creation enterprises in the world of 2030, and a set of refined competencies and learning objectives for future design engineers to be successful in that world.

Individual Assignment 2: In A2, the students build upon their previous assignment plus what has been covered in class over the first couple of weeks. Now their task is to identify what exactly it takes to answer the Q4S. In essence, answering the Q4S can be considered a design problem and the answer to this question can be considered an Open Engineering System they are required to build. The expected outcome of this assignment is a requirements list for an Answer to the Question for the Semester. To learn how to do this, the students start with reverse engineering the requirements list for Open Engineering Systems [22]. Then, they reverse engineer a requirements list for their answer to the Q4S, perform a gap analysis between both lists and refine their requirements list for the answer to the Q4S.

Collaborative Assignment 3: A3 is the first of a number of collaborative assignments. The students are required to experiment with a software suite for virtual collaboration, in which they will interact from this point forth for the remainder of the semester. In addition to becoming familiar with the technical features of the provided collaboration suite, this includes forming a learning community in a distributed setting plus establishing policies regarding collaboration and behavior. In other words, they are required to build a small form of a learning organization [29].

Collaborative Assignment 4 (group project): The topic for A4 is a brief of a collaborative design project. The students are introduced to an open-ended real-world project that has not yet been fully explored. We deliberately provide a very vague and general project brief, and ask the students to 'figure out how to solve it' (see Appendix 1). What we want them to achieve in Assignment 4 is to thoroughly analyze the given problem, understand the crux of it, and determine what needs to be done to address it. This all is to happen in the virtual collaboration suite. As mentioned earlier, an important threshold concept for our students to experience here is that they need to take stock of their individual competencies and determine how all their individual competencies and knowledge can be best leveraged to effectively and efficiently manage the project. In short, we 'crowd-source' the project brief to the entire student body enrolled in our course and expect them to form a learning organization and a self-organizing team of globally distributed contributors.

Collaborative Assignments 5 and 6: Depending on the complexity of the design project from Assignment 4, we may decide to subsequently break it up into two sub-projects of lower complexity to help students get started, if necessary.

A0-EOS and self grading: The final stage of the course is to close the loop with regard to what has been learned, to what level of Bloom's Taxonomy they have managed to climb, and to what degree they have accomplished their learning objectives. This process of reflective practice [30] is presented to the students by means of A0-EOS, an extended end-of-semester version of the original Assignment 0. The students are asked to reflect on their learning process, the quality of their contributions to the various assignments, the value gained with respect to attaining their individual learning objectives and competencies as well as the value added to the overall ME6102 Learning Organization. Finally, based upon this self-reflection, the students are asked to propose a grading rubric for evaluating their own work as well as that of their peers. This includes developing a comprehensive assessment rubric [31] showing the categories of work to be assessed along with justifications for the various degrees of achievement, as well as the articulation of the specific grades they believe they earned.

V. ME6102 – Business Integration and Collaborative Design

In order to provide our students with a more holistic picture of product creation, we believe that the core technical design-related content is best delivered in combination with selected materials that aid the development of ancillary competencies. Some of these ancillary competencies include ideas of product marketing, associated theories of economics, techniques of intellectual-property-centric workflows and innovation-awareness workflows. In particular and in our case, we add a sense of *business integration* within the study of collaborative design principles. We introduce the students to two aspects from the business world, namely Invention to Innovation (I2I) and XBC – Accelerated Business Commercialization Method. Both methods were developed by the RBR Group and are briefly introduced below [24,25].

The speed and agility of entrepreneurial and small businesses; results and best practices at government funded organizations; collaboration of non-competing corporations, and academic research and development today are essential ingredients in the success of an organization's Product Innovation Portfolio, the portfolios the design engineering students will build and grow. The students today will be required to collaborate across the above entities to extract value, and at times supplanting their own work in the market with the acquired innovation to gain competitive advantages for the organization they work for.

I2I (Invention To Innovation) framework introduces the impact of emerging methodologies such as Open Innovation in the market place. In such an environment, speed to market to deliver a unique proposition (i.e. one without any competition) is of far more value than a differentiated value (i.e. one competing against incumbents). See

<http://globalcognition.blogspot.com/2011/02/unique-first-mover-vs-distinctive.html>.

While I2I enables the development of a Product Innovation Portfolio, the validation of the inventions, concepts, etc. captured within it occur through the application of XBC (Accelerated Business Commercialization). XBC educates the students on a method to manage the three key dimensions of their engineering designs in the industry, which include time to market, cost of doing business, and resource requirements. The elements of these dimensions are illustrated in Figure 3.

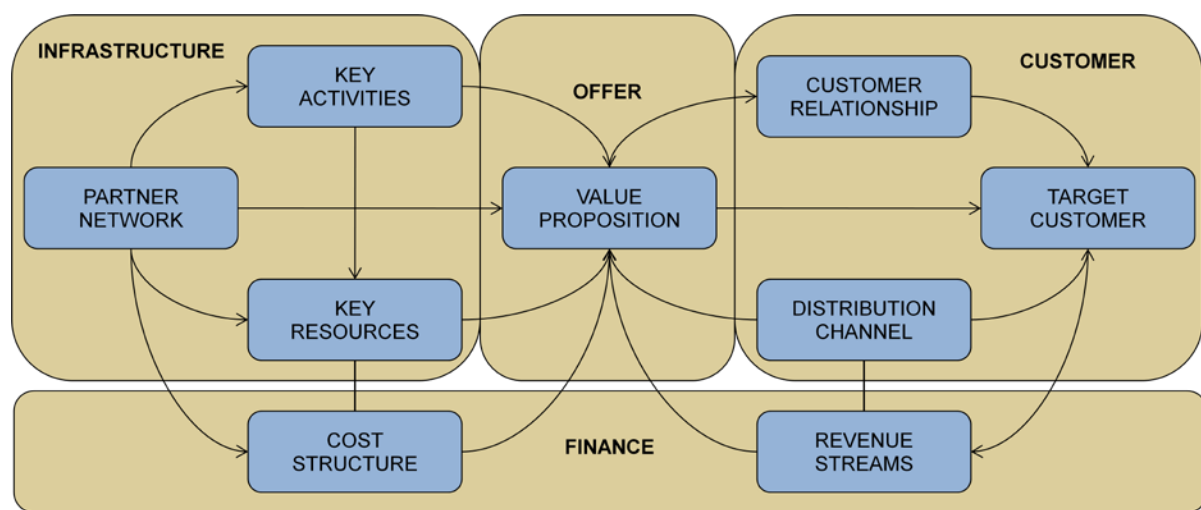


Figure 3: Key dimensions of XBC

XBC enables modeling of a business proposition into nine entities each with interdependencies with others. The students are able to comprehend the complexity of realizing their engineering designs, hence, directly impacting the upstream design process. The result is a robust product to the market versus one that would have to go back to the drawing board.

VI. IT Infrastructure for Distributed Collaborative Design Education

As mentioned before, our Engineering Design course is offered in a Distance Learning setting. This is an important aspect and needs further discussion.

An educational entity needs appropriate technology and infrastructure to facilitate collaborative and collective learning in a globally distributed environment. Figure 4 illustrates, at a high-level, certain aspects of the distance learning environment that has been established at the Georgia Institute of Technology. Georgia Tech has its primary facilities located in Atlanta, GA (GTA) with regional facilities located in Savannah, GA

(GTS). Further, Georgia Tech has international facilities located in Lorraine, France (GTL) and Ireland as well as other micro-sites/facilities both in the US and abroad. Two primary modes of education are in place: synchronous education and asynchronous education.

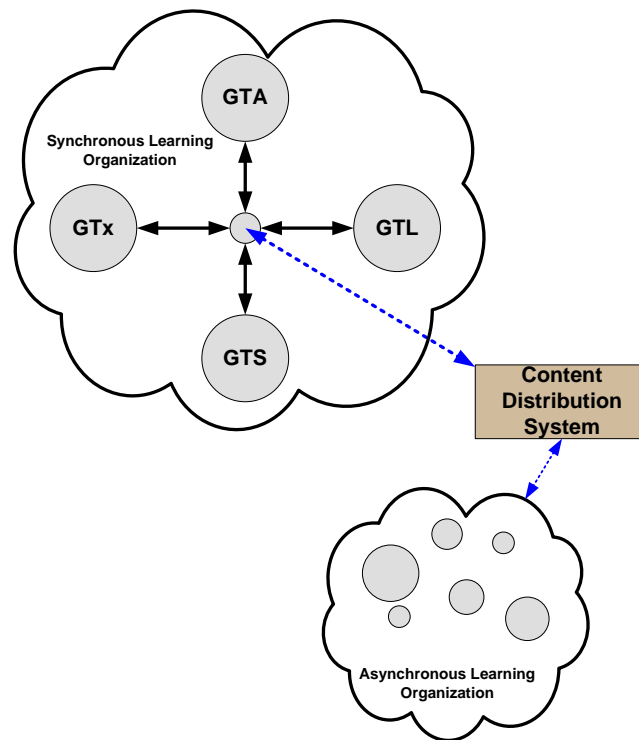


Figure 4: Distance learning environment.

Synchronous operations refer to activities whereby members of the learning organization/community (instructors, students, researchers, etc) meet at scheduled times either in person or virtually. Virtual attendance in synchronous mode is provided by advanced video-telecollaboration (VTC) technologies whereby high-definition video and audio is transmitted over Internet communication technology (ICT). Some of these technologies include Tandberg/Polycom/Cisco video codec and telepresence systems. Classroom activities are virtually interconnected via these types of ICT systems such that members of the geographically distributed learning organization can participate. Because ICT technologies are used for the delivery of real-time (synchronous) coursework, opportunities exist for content capture and archival, which is then re-

distributed via asynchronous education channels. As such, new opportunities of online-education exist, as compared to its current form. Asynchronous learning allows students to retrieve all aspects of archived coursework such as digitally recorded lecture, tutorials, and any form of digitized materials.

In essence, a content distribution system (CDS) is utilized for the delivery and consumption of our synchronous and asynchronous constituents. The concepts illustrated in Figure 4 depict how the geographically separated entities in the “synchronous learning organization” (SLO) interconnect for the delivery of educational content. During the course of SLO delivery, content is captured, archived, and managed. Content is then accessed at a later time by entities of the “asynchronous learning organization” (ALO). ME6102 students consist of both synchronous *and* asynchronous students. We refer to coursework and teaching provided simultaneously to both synchronous and asynchronous students as ‘blended-mode’ content delivery.

A learning management system (LMS) is a key ICT mechanism enabling efficient utilization of educational material (content). Further, we believe it is fundamental component needed for the realization of advanced distance learning environments. LMS are used by many universities, especially those who provide online education programs. The most common utilization of LMS by educational institutes of today is focused on the organization of coursework materials such as lecture notes, tutorials, audio, and video. However, we are working towards advanced LMS that provide a centralized interface into *all* aspects of the university’s learning and research environment. Figure 5 provides a conceptual overview of our content delivery system.

Before continuing our discussion, we should clarify that some components in our CDS, as shown in Figure 5, are in production while others are in prototype states and have not been deployed on a large-scale content delivery basis at this time. In particular, the CloudLabs and ManuClouds systems are prototypes currently under investigation. However, all other components in Figure 5 are in production within our content delivery system.

Our LMS, which we call *Tsquare*, is built on the Sakai learning management framework [38]. Tsquare is a modular and easily-extensible system that provides traditional LMS functionality. Users of the system, which comprise two primary groups being content producers and content consumers, have access to coursework content and are capable of building their own project-specific collaboration sites with just a few clicks of the mouse. The system’s Web 2.0 based interface, which is shown from one perspective in Figure 6, contains numerous features and technologies such as text-audio-video chat, wikis, blogs, RSS feeds, scheduling applications, file archiving, email, and remote desktop sharing. Figure 6 illustrates a particular view of the LMS.

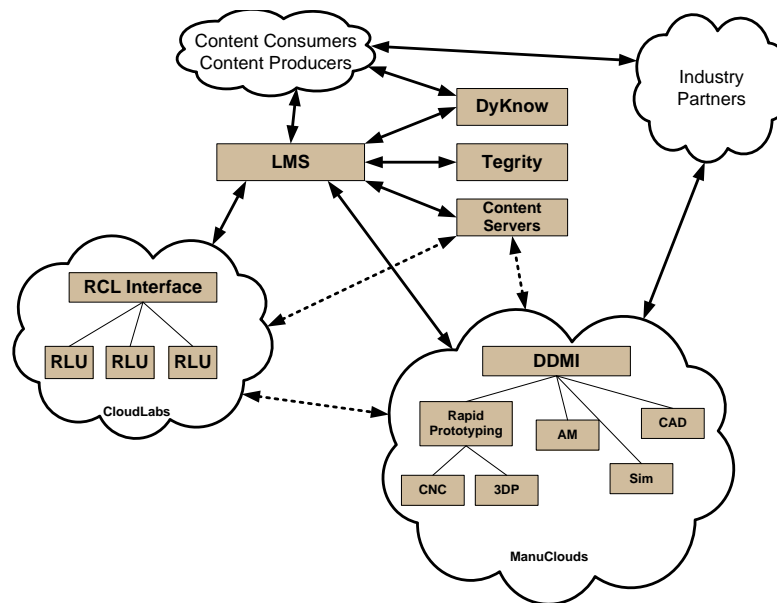


Figure 5: Content delivery system.

Both synchronous and asynchronous students access course content via the LMS. Asynchronous students, further, access the archived video lectures via the LMS or, in certain cases, through a direct ICT link into the digital lecture archives. Both groups of students as well as all others involved in the learning organization use the LMS as *one* particular centralized tool for distributed collaboration. Collaborative design tools used in our learning organization consist of, just to name a few, video chat sessions, multi-point remote desktop sharing (i.e., one desktop ‘controlled’ by many participants such as designing an artifact with CAD software), digital white boards for concept sketching, and interactive mind mapping tools. A nice feature provided by our LMS is that these interactive-at-a-distance collaboration sessions can be digitally recorded and archived for retrieval at a later time.

One feature of educational content creation in its various forms and *simultaneous* capture of it via digital recording is that the content can be archived for later reference by those who created it *and* by anyone else who needs it. In particular, anyone in the learning organization can be content producers and/or content consumers. This aspect facilitates a very rich web of knowledge (content) creation, usage, and ‘cyclic re-usage’ – that is to say, the continual reuse of content as time goes on, which has many benefits if used appropriately.

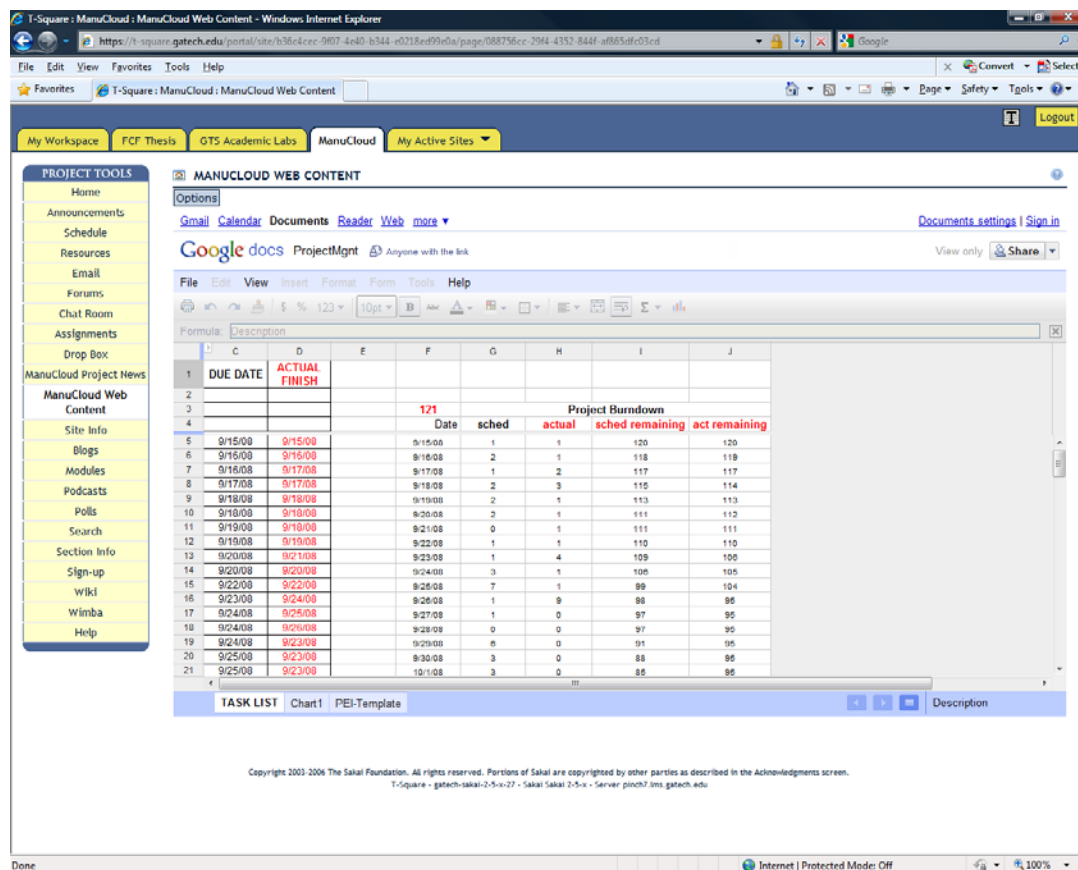


Figure 6: Perspective of the Tsquare LMS.

One simple example of cyclic reuse is the formation of personalized or customized education with 'content chunks'—the idea of “pull a lecture from here and a lecture from there and a book from here and a paper from there....and put them all together”. Mass-customization, which is yet another direct product of advanced ICT and strongly related to mass collaboration and collective learning, is generally a process of interconnecting the pieces of 'something' to produce 'something'. In the case of innovative education, mass-customization of education will consist of interconnecting pieces of educational material—content chunks of archived lecture and other digital materials along with non-archived educational artifacts—to produce a final product of personalized education.

The discussion thus far in this section has revolved around technologies we use in our distance learning setting. However, students participating in distance learning environments for collaborative design can be quite inventive when put to the test. Recall that one of our goals is to teach students the fundamental art of *learning how to learn*. As such, during ME6102 we influence—rather, strategically force—students to go off on their own and search for technologies that are available and *put things together on their own* to aid in distributed collaborative design. A few success stories of the innovative techniques our students have achieved included the use of tools such as Google Docs, Google Groups, Google Sites, Wiggio, and Skype. Some have used the ‘Drupal Content Management System’ to build out their own web-based collaboration tools. In terms of using Skype, one group integrated a multi-point live video session that illustrated a tri-axial robotics demonstration to a group of geographically separated design collaborators. The illustration of our LMS interface shown in Figure 6 is actually a result where students learned how to use the site-building features of our Tsquare LMS to pull in data from other sources, such as Google Docs.

VII. Closing Remarks

In this paper, we presented an overview of our experimentation with innovation in engineering design education in a globally distributed distance learning setting. Revisiting the question posed at the beginning of this paper and reflecting on the observations made over the course of the past five years, we draw the following conclusions: In addition to ever evolving knowledge and technological progress, engineering education is impacted by significant changes in the business environment due to Globalization 3. These changes need to be addressed in our curricula. While technical (core) competencies still are the foundation for success, a number of meta-competencies are required to succeed in the new world of near tomorrow. These include an ability to learn how to learn, an ability to form learning communities, and an ability to collaborate in distributed corporate settings, across countries, continents and cultures. For this to come true, those engineers who wish to become leaders in the world of near tomorrow need to learn how to break with traditional 20th century business models and adjust to what is needed to become a value-adding factor in an interconnected world. In terms of paradigms, this may be considered a shift from ‘team to win’ to ‘share to gain’. The engineer of near tomorrow, a G3 knowledge worker, needs to become a master in creating new knowledge based on a multitude of information and information sources [11].

Overall, the approach described in this paper has worked well. We have experimented with it five times between 2007 and 2011 and approximately 75% of our students fully accomplish the desired learning objectives. As explained before, at the end of the semesters the students are asked to develop a self-grading scheme and propose and justify their own grades. This activity was built into the course as a means to toward achieving level 6 in Bloom’s taxonomy (evaluation). We were pleased to see that the

self-grading for 80% of the students was very much in line with the grades the course orchestrators determined.

At the beginning of the course, many students dislike the idea of having to revisit a specific topic (the Question for the Semester) again and again. However, as the semester progresses and as the students begin to understand and appreciate the value of continuous formative assessment and reflective practice they get accustomed to this. As for the instructor, we have to acknowledge that this course demands a lot of time from the orchestrators. A thorough and successful implementation of the approach described in this paper requires effort that goes beyond traditional lecturing along the lines of 'the professor's notes become the students' notes'. Having said that, and recognizing that research often times takes over our daily business, education still is at the heart of our profession and hence should be practiced with passion – just as our research. With time and experience though, the effort for offering this course decreases, especially if appropriate rubric sheets for marking/grading are used. In summary, we have observed an increase in both student engagement and learning. We are particularly pleased about positive feedback from former students who are now in industry and appreciate the value of what they experienced in this course. In particular, they value the experience they gain in a distributed collaborative setting without any boundaries whatsoever.

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